Dynamics of Soil Organic Carbon under Slash-and-Burn Agricultural Practice in Central Eastern Madagascar

Jeannicq RANDRIANARISOA[1], Herintsitohaina RAZAKAMANARIVO[1], Jocelyn RAKOTONDRAMANANA[1], Tantely RAZAFIMBELO[1], Andry ANDRIAMANANJARA[1], Hery RAZAFIMAHATRATRA[2], Nandrianina RAMIFEHIARIVO[1]

[1] Laboratoire des Radioisotopes, Unité de Recherche Sol et Changement Climatique, Université d'Antananarivo, Route d'Andraisoro BP 3383, Madagascar ; [2] Département Agriculture, Ecole Supérieure des Sciences Agronomiques- Université d'Antananarivo, BP 175, Antananarivo 101, Madagascar ; jeannicq@yahoo.fr

1. Introduction

Slash-and-burn shifting agriculture, locally known as *tavy*, is the predominant land use practice of the Eastern landscape of Madagascar marked by annual depletion of soil fertility leading to the yield reduction (Styger et al 2007). Soil organic matter (SOM) plays an important role in maintaining both soil fertility and quality. Therefore, monitoring of Soil Organic Carbon (SOC) over time could be an important tool to assess the variation of soil quality and fertility over time and guides farmer to a more sustainable land management. Few studies were made on the impact of slash-and-burn on soil carbon dynamics in the Tropics (Kotto-Same et al 1997), and the related recent researches in Madagascar concerned few locations in the Eastern part of the island (Grinand 2010, Razakamanarivo et al 2011, Ramboatiana 2014, Ramifehiarivo 2014). This study aimed to model the variation of SOC over time under slash-and-burn regime.

2. Materials and methods

This study was conducted in the district of Mangoro in Central Eastern Madagascar (Fig. 1) where the landscape is dominated by a mosaic of forest, fallow land and agriculture fields (Styger et al 2007). The yellow on red ferralitic soils are poor in nutrients with a pH ranging from 3.5 to 5.0 and an Aluminium saturation of 60-90%. The studied site belonged to the mid-altitude life zone with an average rainfall of 1,825mm per year and a lot of steep slopes. *Tavy* is the main agriculture system where original forest is cleared, left to dry and burned before subsistence crop, mainly rice, is installed. After few years of crop cycles, the land is temporarily abandoned and the *tavy* system resumes after 3 to 8 years of fallow (Styger et al 2007) but this soil resting period became shorter due to demographic pressure (Vagen et al 2006).

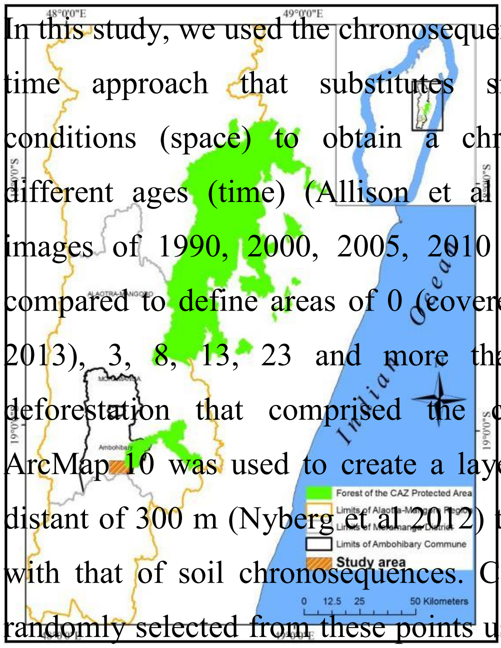

Figure 1: Studied site

In this study, we used the chronosequence or space-for-time approach that substitutes similar soils/site conditions (space) to obtain a chronosequence of different ages (time) (Allison et al 2005). Satellite images of 1990, 2000, 2005, 2010 and 2013 were compared to define areas of 0 (covered with forest in 2013), 3, 8, 13, 23 and more than 23 years of deforestation that comprised the chronosequences. ArcMap 10 was used to create a layer of grid points distant of 300 m (Nyberg et al 2012) that was overlaid with that of soil chronosequences. Center plots were randomly selected from these points using the function RAN() in Excel 2007. Each plot consisted of four sub-plots at the center of each soil pit was dug (Vagen et al 2011). Soil samples were collected with a corer by increment of 10 cm down to 30 cm of depth. SOC stocks were computed using bulk density, the percent of coarse materials that could not pass through the 0.2mm sieve and the carbon contents obtained from the Walkley and Black (1934) method. Various statistical models were then fitted to the SOC stocks data and their coefficient of determination (R^2) along with their Root Mean Squared Error (RMSE) was calculated to select the best model. Contribution of factors other than age of deforestation was determined with Multiple Correspondence Analysis (MCA) with R version 3.0.2.

3. Results and discussion

There is no significant difference between SOC stocks of the various forest conversion ages, and also between those under forest and under slash-and-burn cultivation (*P*=0.08, n=76). SOC stock means showed a high variability ranging from 39.81 to 129.77 MgC/Ha. Rapid increase of SOC stock means immediately after the conversion of forest might be due to the formation of passive pyromorphic humus with weak colloidal properties (Gonzalez-Perez et al 2004, Jobse 2008). Besides, SOC is not immediately released after conversion as tillage is not practiced in the *tavy* cultivation system.

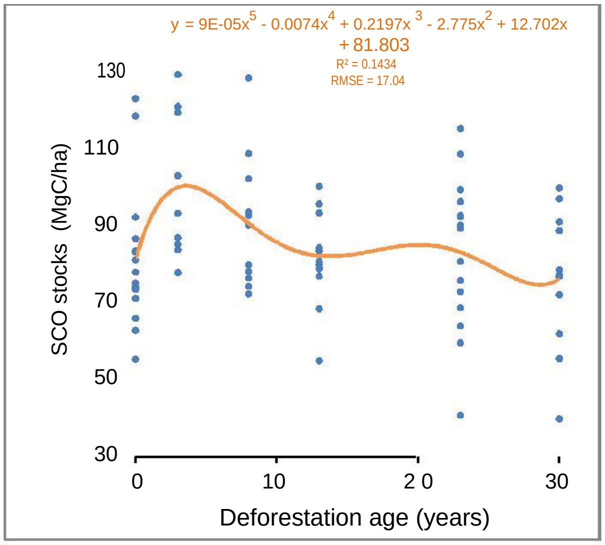

Figure 2: SOC dynamics model

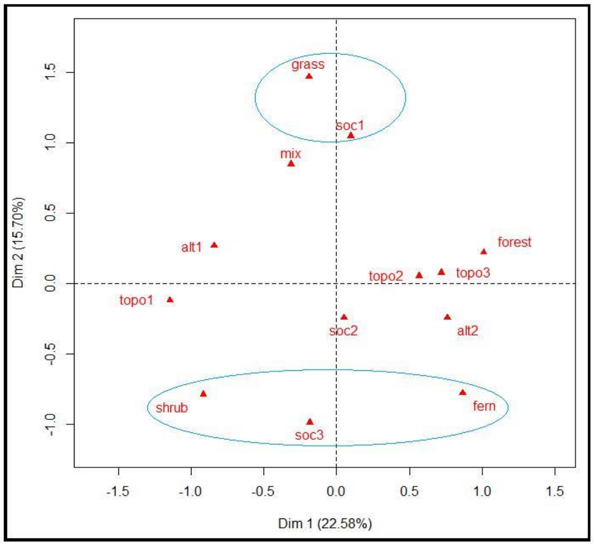

Figure 3: Graph of modalities

However, repeated fires increased the impact of erosion which progressively depleted the soil of its carbon and nutrient contents. Conversion age seemed to explain only 14% of SOC variations (Fig. 2). MCA suggested an important contribution of the vegetation type on SOC values (Fig. 3) where grass SOC stocks were significantly different from those of shrub and fern, with respectively *P*=0.005 and *P*=0.008. This supports the findings of Grinand (2010), and also that of Kotto-Same et al (1997) where SOC reaccumulated in the recovering fallows.

4. Conclusion

Chronosequence alone does not allow for a reliable monitoring and eventually prediction of SOC stock since it varies with the dominant vegetation type. Consideration of this latter is then critical when sampling for SOC studies. Regressive fallows lead to the formation of grassy vegetation with the lowest SOC stock, whereas agricultural practices that favor woody vegetation enhance SOC stocks while preventing fertility decline. These findings support the necessity to boost agroforestry systems adapted to farmer needs and less or no-fire practices to ensure a more sustainable rural development.

5. References

Allison V.J., Miller R.M., Jastrow J.D., Matamala R. & Zak D.R. 2005. Changes in soil microbial community in tallgrass prairie chronosequence. Soil Science Society of America Journal 69: 1412-1421.

Grinand C. 2010. Développement d'une méthode de spatialisation des stocks de carbone du sol à l'échelle régionale, mémoire Mastère SILAT, 47p

Jobse J. 2008. Impacts of forest-to-agriculture conversion on aboveground and soil carbon and nitrogen stocks along a bioclimatic gradient in Costa Rica. Ph. D. Dissertation. Oregon State University.

Kotto-Same J., Woomer P.L., Appolinaire M. & Louis Z. 1997. Carbon dynamics in slash-and-burn agriculture and land use alternatives of the humid forest zone in Cameroon. Agriculture, Ecosystems and Environment 65: 245-256

Nyberg G., Tobella A.B., Kinyangi J. & Ilstedt. 2012. Soil property over a 120-yr chronosequence from forest to agriculture n wester Kenya. Hydrol. Earth Syst. Sci. 16: 2085-2094.

Ramboatiana N. 2014. Modélisation des émissions de CO2 des sols après déforestation : Estimation a l'échelle d'un paysage. Cas du paysage forestier de Beapingaratsy, Région Anosy. Mémoire de DEA, ESSA-Forêts.

Ramifehiarivo, N. 2014. Evaluation des stocks de carbone du sol après déforestation : Cas de Moramanga. Mémoire de fin d'études d'ingéniorat. Ecole Supérieure des Sciences Agronomiques, Département Agriculture.

Razakamanarivo R. H., Razafimahatratra H. & Razafimbelo T. 2011. Modélisation des pertes de carbones organiques dans les sols après déforestation. Rapport final. LRI, Good Planet.

Styger E., Rakotondramasy H.M., Pfeffer M.J., Fernandes E.C.M. & Bates D.M. 2007. Influence of slash-and-burn farming practices on fallow succession. Agriculture, Ecosystems and Environment 119 : 257–269.

Vagen T., Winowiecki L., Desta L.T. & Tondoh J.E. 2011. Field Guide. LDSF - AFSIS

Vagen T-G., Andrianorofanomezana M-A.A. & Andrianorofanomezana. 2006. Deforestation and cultivation effects on characteristics of oxisols in the highlands of Madagascar. Geoderma 131: 190 – 200.

Walkley, A. & Black I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29-38.